Outplanting Anadromous Salmonids

A Literature Survey

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ABSTRACT

This paper presents a list of more than 200 references on topics associated with offstation releases of hatchery stocks of anadromous fish used to supplement or reestablish wild rearing. The narrative briefly reviews influences of genetics, rearing density of fish in the natural evironment, survival rates observed from outplanted stocks, and estimation procedures for stocking rates and rearing densities. We have attempted to summarize guidelines and recommendations for fishery managers to consider.

Contract obligations require that we offer specific information related to spring chinook salmon in the Willamette River. Based on tagging studies, a typical smolt release from a Willamette River hatchery would return 0.29% of the smolts to the stream of release as adults. Catch to escapement ratios for adult Willamette chinook vary widely between broods, but on average two fish are caught for each fish that escapes. The catch is about evenly divided between offshore and freshwater harvest. British Columbia is the primary location of offshore harvest, and the lower Willamette River is the primary location of freshwater harvest.

Review of departmental policy indicates that only Willamette stock spring chinook are currently acceptable for use in a proposed outplant study within the Willamette basin. Further, most Oregon Department of Fish and Wildlife district management biologists would prefer not to transfer any stocks of spring chinook between drainage subbasins.

State fishery managers identified 16 Willamette basin streams as being suitable for supplementation with spring chinook from hatcheries. We reviewed the potential for rearing salmon in reservoirs throughout the basin.

Use of the Carmen-Smith spawning channel, which was constructed on the upper McKenzie River in 1960, has generally declined with the decline in populations of chinook salmon in this river. The Carmen-Smith channel still provides a spawning place for those relatively few adult chinook that still return each year, but more fishery benefits may result from other uses of this facility.

INTRODUCTION

In a recent study of outplanting salmon from hatcheries, Tom Nickelson and Mario Solazzi (DDFW, in process) observed the effects of releasing presmolts of early-spawning coho into coastal streams where populations of wild late-spawning coho are low. Evaluation of results showed that the stocked streams reared more total juveniles, but that wild juveniles were displaced by hatchery fish. Further, when adults that originated from hatchery outplants returned to spawn, recruitment was markedly reduced. The investigators concluded that outplanting of coho presmolts from hatcheries, once a major thrust of Oregon's STEP program, lacked biological benefit.

A review of the literature on supplementation reveals that much depends on the expectations and circumstances surrounding an outplant program. With coastal coho, protection of the residual populations of wild coho was a major concern. Would the conclusions have been as negative if the test streams had been depleted of salmon? Would the conclusions have changed if locally-adapted, late-spawning stocks of coho presmolts had been used in the study? And what would have been the conclusion if the study results had been expressed in terms of increases in rearing density of juvenile fish?

In this paper we have listed as many written references to "outplant" situations as we could collect, we have synthesized some of the most pertinent written observations into rough guidelines and recommendations, and we have answered some specific questions about spring chinook in the Willamette Basin. Finally, we propose an outplant study using appropriate stocks of Willamette spring chinook released into stream areas that contain few residual wild chinook, and we propose using changes in the number of adults that return as the measure of success.

Our conclusion is that salmon management of the future will involve frequent attempts to integrate hatchery stocks into dwindling wild populations. If the references and comments we have listed help to make better-informed decisions, then this exercise will have been worthwhile.

DESCRIPTION OF STUDY AREA, MATERIALS, AND METHODS

This literature review was conducted by personnel in the Research and Development Section of the Oregon Department of Fish and Wildlife (ODFW) stationed at Corvallis, Oregon. The respective libraries of ODFW and of Oregon State University were the primary sources of literature and references. Reviewers contacted biologists working in the Pacific Northwest to obtain unpublished data and opinions related to the subject of outplanting.

RESULTS AND DISCUSSION

The first objective (Objective 1.1) of this study was to provide a report that summarized results of previous outplant efforts and related data as requested by Bonneville-Power Administration (BPA) and the Northwest Power Planning Council (NPPC). The second objective (Objective 1.2) was to identify methodology and requirements for evaluation of test results.

Objective 1.1

We present a review of information available on the supplementation of wild stocks with excess hatchery fish to take advantage of underused freshwater habitat. The purpose of this review is to provide information pertinent to the development of a detailed study plan designed to determine the most effective method of supplementing wild Willamette River spring chinook salmon with outplanted hatchery-produced fish.

We define outplanting as releasing fish from hatcheries at locations away from the hatchery to increase natural production in streams determined to be seeded or used at less than "optimal levels". Few studies specifically evaluating the success or impact of outplanting have been conducted. We also present a "Supplementation Literature" section (Appendix B) that includes additional references and unpublished data supplied from various state and federal sources.

Task 1.11.

We summarize available literature on outplanting of hatchery stocks and pertinent information on factors that influence success of an outplant program--density, survival, genetics, competition, and predictor models for assessing carrying capacity of a stream area. Several predictor models and methods used for estimating rearing capacity and stocking rates are reviewed. We also made recommendations based on this literature review.

<u>Density:</u> A major factor influencing the success of an outplant program is the density at which the fish are stocked. Ideally, an "optimum" level of stocking would have minimum impact on wild juvenile salmonids residing in the stream and would provide a maximum number of smolts from the stream system. Determining an optimum level of stocking requires an evaluation of the magnitude and quality of habitat available for rearing juvenile salmonids. In streams with natural production, it is possible to proceed with available predictive models or non-deterministic methods to assess the desired smolt yield, or density of fish, for a given stream system. After the desired density of fish is determined, it is possible to apply estimates of survival rates for all life history stages to calculate a desired level of "stocking rate". Therefore, in addition to information on the habitat of the stream system considered for outplanting, a fisheries manager requires information on survival rates and densities of those species for which the stream is to be managed.

Food and space are thought to be the most important factors influencing fish density in streams (Larkin 1956). Space requirements of juvenile salmonids in streams vary with species, age, and time of year and are related to the overall productivity (food abundance) of the stream (Chapman 1966). Physical factors that control densities of salmonids include discharge, stream morphology (pools, riffles, glides), riparian and instream cover, and type of substrate (Giger 1973; Reiser and Bjornn 1979). Other factors that influence density of allopatric and sympatric populations of salmonids and that change with developmental stage are habitat preferences, social interaction, and predator-caused mortality (Hartman 1965; Lister and Genoe 1970; Everest and Chapman 1972; Stein et al. 1972).

Table 1 shows a range of densities at varying life history stages for chinook and coho salmon, and steelhead in several river basins. Most subyearling chinook are found at densities below 0.3, fish/sq m (Figure 1). Subyearling steelhead are found at 0.01 to 0.7 fish/sq m with no consistent trend between river systems, whereas most yearling and older steelhead were found below 0.2 fish/sq m. Subyearling and yearling coho were mainly found at densities below 0.4 fish/sq m. The spread in densities observed results partly from differences in natural or artificial stocking densities, size of stream, and habitat quality. These findings are consistent with data on densities of salmonids in streams assembled by Allen (1969b) who found a positive correlation between area per fish and age and length. He concluded that densities of 10 cm salmonids averaged around 0.17 fish/sq m (1.7 g/sq m). Densities of age 0 trout and salmon at the end of their first summer (70 to 120 mm) average around 0.2 fish/sq m, whereas yearlings and older fish average 0.06 to 0.5 fish/sq m.

Survival: In general, survival is dependent upon the level of productivity and rearing capacity of the stream system. For a given capacity of stream to rear juvenile salmonids, factors that may influence survival of outplanted fish introduced into a system include competition with wild fish and outplanted cohorts, predation level, incubation and rearing environment prior to release, genetics (origin of stock), and age or size at release. For those species or stocks that over-winter and migrate as yearlings, additional factors that influence survival are magnitude of winter freshets and suitability of habitat to hold over-wintering fish (Mason 1976b).

Several investigators have estimated survival from egg to subsequent life history stages based on potential egg deposition determined from measured or estimated spawning escapement figures and average fecundity data (Table 2). Estimates of fry survival have been limited to evaluations of fry plants where number of fry released is known because it is difficult to obtain estimates of both natural fry production and outmigrant smolts within a system.

Bjornn (1978) evaluated natural production of spring chinook in the Lemhi River, Idaho, and over an 8-year period found that survival from egg to migrant smolt averaged 9.8% (range 4.0% to 15.9%). He considered the level of spawning escapements to the upper Lemhi River low during the study years, thus underseeding may have resulted in maximum survival rates for juvenile chinook in that system.

Table 1. Mean density/biomass of juvenile chinook, coho salmon, and rainbow steelhead trout at varying life history stages.

			Mean density/biomass					
			Chinook		Rainbow/steelhead		Coho	
Investigator	Location	Age or season	fish/sq m	g/sq m	fish/sq m	g/sq m	fish/sq m	g/sq m
Bjornn 1978	Big Springs Cr., Idaho	End of summer	2.08	18.0	0.93	7.8		
Bjornn 1978	Big Springs Cr., Idaho	Winter	1.40	12.5	0.54	4.3		
Bjornn 1978	Upper Lemhi R., Idaho	End of summer	1.29	21.4	0.70	16.0		
Bjornn 1978	Upper Lemhi R., Idaho	Winter	0.61	14.2	0.13	9.9		
K. Schroeder, Uunpub.)	White R., Oregon	Age 1+	0.08		0.10			
Cates, USFWS, unpub. data	Warm Springs R., Oregon	Age 0	0.05		0.05			
Burck et al., 1979, 1980	John Day R., Oregon	Age 0	0.19		0.80 (age 0+)			
Crawford et al. 1984	Wind R., Washington	Age 0	0.09		0.12			
J. Mullan, unpub. data	Wenatchee R., Washington	Age 0	0.08	0.38.	0.04	0.34		
J. Mullan, unpub. data	Entiat R., Washington	Age 0	0.06	0.05	0.08	1.0		
Sekulich 1980	Salmon R., Idaho	Age 0	0.26	0.86	0.11			
Gamblin 1984	Clearwater R., Idaho	Age 0	0.25		0.08			
Anderson 1984	Western Oregon streams	Age 1+			0.11		0.99 (parr)	
J. Buell, unpub. data	Manzanita Ck., California	Age 0			0.69	1.36		
J. Buell, unpub. data	Trinity R., California	Age 1+			0.23	4.80		
Platts and Partridge 1978	S.F. Salmon R., Idaho		0.06					
Marshall et al. 1980	Cowichan R., B.C.	Age 3 mo.	0.18	0.64				
Marshall et al. 1980	Big Qualicum R., B.C.	Age 3 mo.	0.30	1.22	0.021	0.94		
Marshall et al. 1980	Snow Cr., Washington	Smolt			0.022	1.00		
Marshall et al. 1980	Salmon Cr. Washington	Smolt			0.017	0.83		
Marshall et al. 1980	Carnation Cr., B.C.	Smolt			0.006	0.20		
Marshall et al. 1980	Keogh R., B.C.	Smolt			0.016	0.73		
Irving et al. 1983	S.F. Clearwater R., Idaho	Age 0			0.34			
Irving et al. 1983	S.F. Clearwater R., Idaho	Age 1+			0.44			
J. Newton, unpub. data	Fifteen Mile Cr., Washington	All ages			0.62			
Burns 1971	Yager Ckr, California				0.90	3.46		
Burns 1971	Godwood Cr., Cal.	All ages			0.14	0.52	0.26	0.73
Burns 1971	N. Casper Ck., Cal.	All ages			0.64	1.35	0.19	0.38
Everest and Sedall 1983	Fish Ck., Wash. Cr., Oregon		0.01	0.06	0.61	3.98	0.10	0.56
USFW, unpublished	Warm Springs R., Shitike Cr.		0.05 (age 0)	0.28	0.04 (age 1+)	0.76		
Maciolek 1979	Trout Cr., Oregon	Mid-August			0.69	2.29		
Maciolek 1979	Bakeoven Cr., Oregon	Late July			2.65	9.16		
Maciolek 1979	Buck Hollow Cr., Oregon	Late July			7.32	26.78		
Maciolek 1979	S.F. John Day R., Oregon	Early September			0.03	2.18		
Maciolek 1979	N.F. John Day R., Oregon	Early September	0.05	0.37	0.08	1.87	(all ages)	
Maciolek 1979	Chesnimus Cr., Oregon	Late July			0.61	4.66		
Maciolek 1979	Umatilla R., Oregon	Early August			0.77	8.69		
Maciolek 1979	Meacham Cr., Oregon	Mid-August			0.36	3.84		
Maciolek 1979	Camp Cr., Oregon	Mid-August			0.87	6.60		
Maciolek 1979	Camp Cr., Oregon	mid-August			0.87	6.60		
Maciolek 1979	Snow Cr., Washington	Fry			0.70			
Maciolek 1979	Snow Cr., Washington	Smolt			0.03			
R. Hooten, unpub. data	Quinsam R., B.C.	Smolt			0.02			
P. Slaney, unpub. data	Keogh R., B.C.	Smolt	0.027					
McGie 1985, unpublished	Siltez, Nestucca R., Oregon	Fry	0.72					
Chilcote et al. 1984	Gobar Cr., Washington	Smolt			0.037			
Chilcote et al. 1984	Kalama R., Washington	Smolt	0.073					
Solazzi, et al. 1983	Oregon coastal streams	August					0.56 (stocked)	
Solazzi, et al.1983	Oreogn coastal streams	August					0.37 (unstocked)	
Mabbott 1982	Lochsa R., Idaho	August	0.032		0.338 (age 0)			

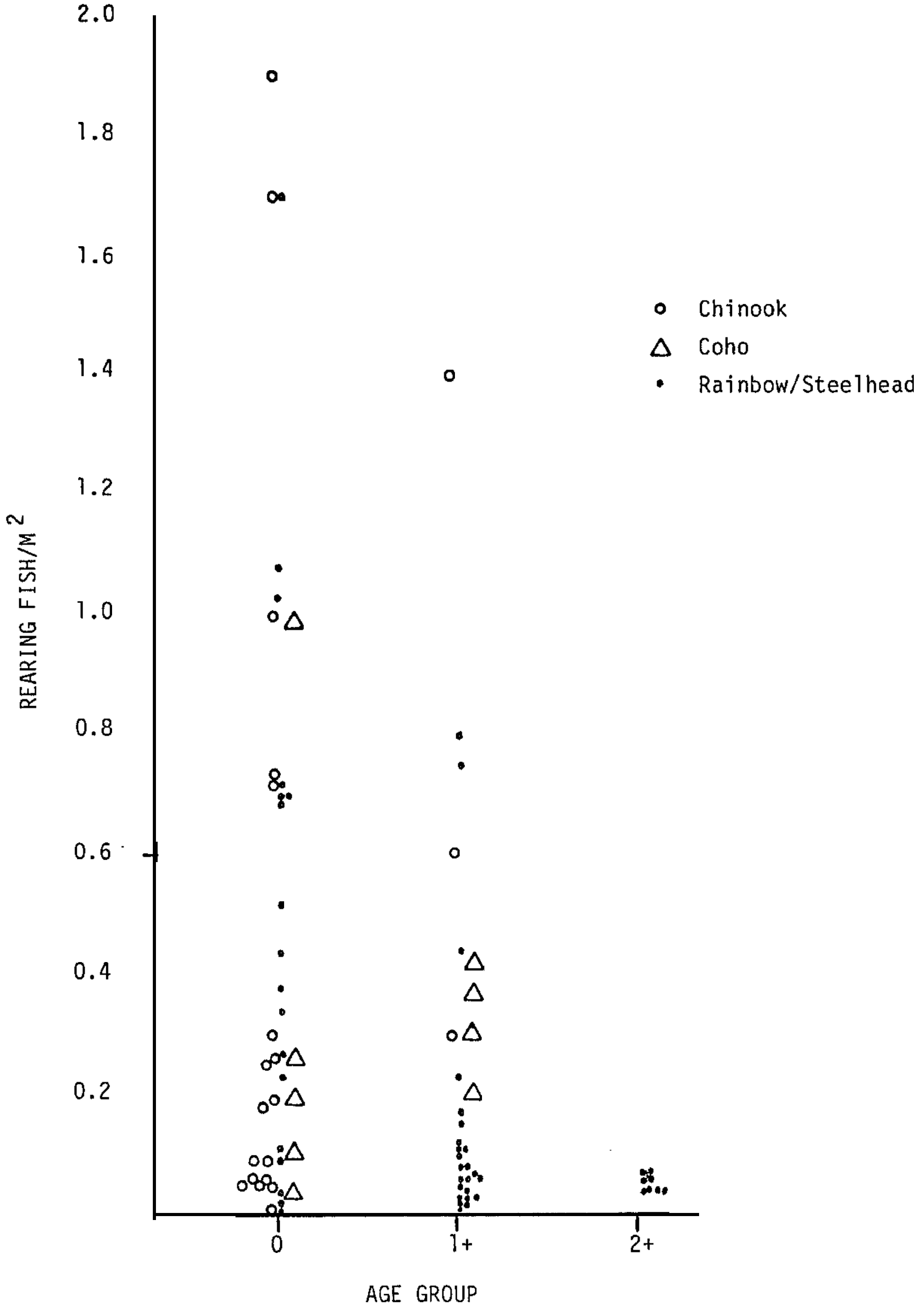

Figure 1. Reported densities of juvenile anadromous fish in streams (Table 1 and Allen, 1969).

In the Deschutes River, Oregon, Jonasson and Lindsay (1983) found an average egg-to-migrant survival rate of 3.5 percent (range 2.3% to 5.5%) spring chinook smolts. These were primarily yearling spring migrants but also included fall (age 0) migrants. An egg-to-migrant survival rate of 5.2% (range 3.6% to 6.7%) was found for spring chinook in the John Day River, Oregon, (Lindsay et al. 1981). These percentages were based on yearling spring migrants only. A somewhat higher survival estimate of egg to migrant smolt was made by Major and Mighell (1969) who reported egg-to-migrant survival rates averaging 10.9% (range 5.4% to 16.4%) for spring chinook in the Yakima River, Washington.

Burck (1974) found an average 9.5% survival (range 6.4% to 13.8%) from egg-to-fall-migrant spring chinook out of Lookingglass Creek, a tributary of the Grande Ronde River, Oregon. These fish migrated to the ocean in the spring as yearlings, therefore additional mortality may have occurred to subyearling fish that have over-wintered downstream in the Grande Ronde or Snake rivers. Survival to a presmolt migrant stage was also estimated by Lister and Walker (1966) who evaluated streamflow control on natural production of fall chinook in the Big Qualicum River, British Columbia. Survival from egg to a June (age 0) migrant averaged 3.4% (range 0.1% to 7.9%).

Additional information on presmolt survival comes from evaluations of naturally produced juvenile steelhead (Table 2). Steelhead survival rate estimates from potential egg deposition to migrant smolt averaged 0.01% in the North Umpqua River, Oregon (personal communication during June 1985 with Alan McGie, Oregon Department of Fish and Wildlife, Research and Development Section, Corvallis, Oregon), 0.56% to 1.71% in Snow Creek, Washington (Washington Department of Fisheries, unpublished data), and 0.32% to 0.64% in the Keogh river, British Columbia (British Columbia Ministry of Environment, Fisheries Branch, unpublished data).

The preceeding estimates of survival from eggs to fingerlings or to smolts are particularly useful when assessing the value of hauling mature adults to stream reaches considered underseeded, suitable for spawning, and capable of supporting increased numbers of juvenile salmonids. Assessing the potential of other supplementation techniques such as streamside incubators, egg plants (e.g., Vibert boxes), and presmolt outplants requires additional information on egg-to-fry and fry-to-smolt survival rates.

A summary of egg-to-emergent-fry survival for streamside incubators in Oregon is shown in Table 3 (memorandum dated May 21, 1985 from Richard L. Berry, Oregon Department Fish and Wildlife, Portland, Oregon). Percent survival of combined spring and fall chinook for the 1982-83 through 1984-85 brood-years averaged 79.3%. Estimates of egg-to-fry survival, based on early-migrant fry trapped soon after emergence in close proximity to spawning areas of known escapement, are shown in Table 2. Egg-to-fry survival estimates ranged from 14.5% to 20.6% for chinook salmon and from 7.9% to 20.6% for pink salmon.

Table 2. Mean percent survival rate of juvenile chinook, coho, pink salmon, and steelhead trout from early to subsequent life history stages.

Species, investigator	Location	Mean percent survival rate: Egg-to-fry	Egg-to-smolt	Fry-to-smelt
Spring chinook salmon:				
Bjornn 1978	Lemhi R., Idaho	20.6	9.8	21.2[a]
Jonasson and Lindsay 1983	Warm Springs R., Oregon		3.5	
Lindsay et al. 1981	John Day R., Oregon		5.2	
Major and Mighell 1969	Yakima R., Washington	10.9		
Burck 1974	Lookingglass Cr., Oregon	0.9		
Smith 1976	Fall Ck. Reservoir, Oregonn			12.4[b]
Fall chinook salmon:				
Lister and Walker 1966	Big Qualicum R., B.C.	19.8		
Wales and Coots 1954	Fall Cr., Klamath R., California	14.5		
Coho salmon:				
Rothfus et al. 1974	Speelyai Cr., Washington			5.7
Rothfus et al. 1974	Speelyai Cr., Washington			10.6 - 27.1[c]
McIssac 1977	3 creeks in Washington			0.43
Washington Dept. Fish, unpub.	White Salmon R., Washington			7.7[d]
Washington Dept. Fish, unpub.	Green R., Washington			1.3[e]
Hostick & McGie 1974	Floras Lake, Oregon			2.3
Phinney 1965	9 lakes in Washington			26.5
Pink salmon:				
McNeil et al. 1969	Sashin Cr., Baranof Is., Alaska	13.0		
Barns 1974	Tsolum R., B.C.	20.6		
Bailey 1976	Auke Cr., Alaska	7.9		
Steelhead:				
A. McGie, unpub. data	N.F. Umpqua R., Oregon		0.01	
Bjornn 1978	Lemhi R., Big Springs Cr., Idaho			2.0
Bjornn 1978	Snow Cr., Washington			4.6
P. Slaney, unpub. data	Keogh R., B.C.		0.51	
Chilcote et al. 1984	Gobar Cr., Washington		0.09[f]	
	Kalama R., Washington		0.86	

a *Presmolts released at 500/lb in 1973 and 398/lb in 1974.*
b *Presmolts released at an average Length of 75 mm in 1970 and 56 mm in 1971.*
c *Survival of fingerlings to molt.*
d *Fingerlings released at lOO/Lb.*
e *1.3% at trap site; estimated total 3.0% survival.*
f *Excluding migrant parr; 0.23% survival including migrant parr.*

Table 3. Mean percent survival of egg to emergent fry for streamside incubators in Oregon, all river systems combined.

Species	Brood year 1982-83	1983-84	1984-85
Spring chinook salmon	88.5	27.8	73.5
Fall chinook salmon	(a)	89.4	79.3
Coho salmon	(a)	78.0	83.1
Summer steelhead		85.6	93.0
Winter steelhead	(a)	89.5	89.0

a Not available.

Although many river systems have a history of hatchery supplementation using outplants of presmolts, few evaluations of this method have been conducted. Bjornn (1978) evaluated outplants of spring chinook fingerlings into Big Springs Creek, Idaho, in 1970 (average length 75 mm) and 1971 (average length 56 mm) and estimated survival to migrant smolts to be 20.9% and 21.6%, respectively. In the same study, Bjornn (1978) outplanted steelhead fry and found survival to yearling migrants averaged 2.0% (range 1.5% to 3.8%). Steelhead fry-to-smolt survival estimates made in Snow Creek, Washington (Washington Department of Fisheries, unpublished data), averaged 4.6% (range 2.2% to 6.7%).

In Speelyai Creek, Washington, Rothfus et al. (1974) estimated fry-to-smolt survival of planted coho fry at 5.7%. McIsaac (1977) evaluated outplants of unfed coho fry in three creeks in Washington and found survival rates from 0.19% to 0.79%, but his results were based on small sample sizes. Studies in the White Salmon River, Washington (Washington Department of Fisheries, unpublished data), showed an average 7.7% survival to smolt (range 6.4% to 9.0%) from coho fry released at 100/lb. In the Green River, Washington (Washington Department of Fisheries, unpublished data), 1.3% of outplanted coho fry survived to smolt based on the number of fish recovered at the trap site, but an estimated total of 3.0% survived to smolt in that system.

Genetics: Ricker (1972) defines a stock as "the fish spawning in a particular lake or stream (or portion thereof) at a particular season, which . . . to a substantial degree do not interbreed with any group spawning in a different place, or in the same place at a different season." This reproductive isolation may create a genetically and phenotypically unique stock of fish that are adapted to the environmental characteristics of the stream in which they evolved. Endemic stocks of fish are continually subject to natural selection that maximizes fitness, or the potential of the population to successfully produce fertile offspring.

Stocks of fish adapted to a hatchery environment may differ substantially from their native progenitors in terms of their fitness in a natural stream environment. Hatchery stocks may undergo interbreeding, protection of unfit genotypes, and artificial selection for traits that may be desirable in a hatchery environment but undesirable in a natural environment.

An important concern of outplanting hatchery fish to increase natural production in a stream is the potential for genetically altering populations of naturally spawning fish. Reisenbichler (1984) developed a simple genetic model (one gene locus with two alleles) to incorporate gene flow and density-dependent mortality. Computer simulation of this model showed that density-dependent mortality and gene flow constitute a potent force for eliminating advantageous alleles and, by inference, for causing other potentially damaging genetic changes in wild fish populations.

Reisenbichler and McIntyre (1977) measured growth and survival of offspring from matings of hatchery and wild Deschutes River summer steelhead to determine if hatchery fish differ genetically from wild fish in traits that can affect stock-recruitment relationships of wild populations. Sections of four natural streams and a hatchery pond were stocked with genetically marked (lactate dehydrogenase genotyes) eyed eggs or unfed fry from each of three matings: hatchery X hatchery (HH), hatchery X wild (HW), and wild X wild (WW). In streams, WW fish had the highest survival and HW fish the highest growth rates. In the hatchery, HH fish had the highest survival and growth rates. They concluded that hatchery fish were genetically different from wild fish and when they interbreed with wild fish, production of smolts may be reduced.

Genetic analysis of the 1979 brood steelhead smolts in Gobar Creek, Washington (Chilcote et al. 1982), indicated that WW mating produced 19% more smolts than HW matings and 72% more smolts than HH matings. Analysis of the 1980 brood steelhead in Gobar Creek showed a similar pattern: WW matings produced 13 percent and 54 percent more smolts than HW and HH matings, respectively. Additional data collected in 1981 and 1982 (Chilcote, et al. 1984) indicated that wild steelhead spawners were 270% more capable of contributing to the natural production of subyearling steelhead in the Kalama River, Washington, than were spawners of hatchery stock. A preliminary evaluation of smolt data in the Kalama River suggested that the reproductive fitness of wild steelhead may exceed the reproductive fitness of hatchery steelhead by 600%. Chilcote et al. (1984) presented evidence that the observed differences in reproductive success between hatchery and wild steelhead may be due to (1) early, nonadaptive spawning of hatchery fish, resulting from artificial selection for early spawning fish, and (2) an inherent (yet unknown) competitive advantage of fry from wild parents over fry from hatchery parents.

Evidence of reduced survival in progeny from adults that survived from outplanted hatchery presmolts comes from preliminary results of coho presmolt evaluations in Oregon coastal streams (personal communication during June 1985 with Mario Solazzi, Oregon Department of Fish and Wildlife, Research and Development Section, Corvallis, Oregon). Adult returns from hatchery presmolt releases were not significantly different from adult returns to control streams that were not stocked; however, juvenile densities in the treatment streams that resulted from adults that returned from presmolt' releases were significantly lower than juvenile densities measured in the control streams.

Miller (1954) compared the survival and growth of hatchery fry and wild cutthroat trout fry planted in enclosed stream sections. Survival of hatchery fish was 0% to 4.9% over the first winter and 0% to 3.1% over the second winter, compared with 46.0% and 29.0% survival, respectively, for wild fish. Also, hatchery fish grew more slowly than wild fish. Miller (1954) concluded that the low survival rate of hatchery fish was due to the absence of natural selection at early stages in their life history.

These studies suggest that outplants of hatchery fish may cause genetic change in endemic populations and that such changes may persist even if outplanting is discontinued. A basic assumption to this premise is that hatchery stocks are genetically different from the wild stocks that are being supplemented. In a review of the genetic implications of stocking hatchery trout on native populations, Nicholas et al. (1978) suggested that hatchery practices can be modified to produce fish that are genetically similar to native fish in a particular watershed. This process involves developing new hatchery strains and introducing native stocks back into the hatchery population, avoiding artificial selection for traits that differ from those of wild spawning populations, and minimizing interbreeding. These techniques have been used to supplement the wild stock of fall chinook in Elk River, Oregon, with hatchery-reared fish (Reimers 1978). In that hatchery program, wild Elk River spawners were captured to establish the original broodstock. Since then hatchery practices have been developed in an attempt to avoid altering the biological characteristics or the production of the native fall chinook population. These practices include (1) collecting eggs from throughout the spawning run (November through February), and (2) maintaining genetic variability and reducing inbreeding by including wild fish in the egg-take, using one male for every female spawned, and by crossing all age lines of returning spawners (Nicholas et al. 1985).

During the first 11 brood years of hatchery returns to Elk River, the hatchery component of the spawning escapement averaged approximately two-thirds of the run. Many of these hatchery fish inbreed with wild fish in Elk River (Burck and Reimers 1978). In addition, annual releases of up to 634,000 hatchery spawned unfed fry were made from 1977 to 1984 in several upriver tributaries (personal communication during July 1985 with Timothy Downey, Oregon Department Fish and Wildlife, Research and Development Section, Port Orford, Oregon). Despite these potential effects on wild production, the wild component of spawning escapement to the system has remained relatively stable, and no significant change in the biological characteristics of the wild populations are evident.

Competition: The physical environment of a stream system determines the overall rearing capacity and provides the framework within which biological characteristics of the fish population regulate the density and survival of each species. One mechanism that regulates density and survival is intra-specific and interspecific competition for limited resources (Chapman 1966). Amount of habitat and, to some degree, of food are limited resources within a stream. Competition for these resources may be the basis for establishment of territories and size-hierarchies by juvenile fish within the appropriate habitat for a particular species.

The acquisition of optimal feeding stations or territories is of survival benefit to individual fish. Despotic fish in hierarchies or successful territorial fish grow more rapidly than subordinates or refugees (Kalleberg 1958; McPhee 1961; Chapman 1962; Mason and Chapman 1965). Reimers (1968) found that dominance-subordination relationships among juvenile fall chinook salmon were largely determined on the basis of size, Dominant fish, in possession of the best terrritories relative to food and shelter, were the largest. Chapman (1962) and Mason and Chapman (1965) found similar relationships for juvenile coho salmon in streams. Early-emerging coho fry were, on the average, larger and more abundant within terminal populations than late-emerging fry,and were occupying the most upstream areas within the stream channels. They concluded the number and size distribution of coho throughout the stream channels was associated with feedinq opportunity and food availability levels, competition, and behavioral dominance through aggressive behavior.

Chapman (1962) has shown that aggressive behavior associated with intraspecific competition for food and space is an important cause of downstream movement of coho fry prior to smolt migration. Lister and Walker (1966) hypothesized that density-dependent factors may be important in the early migration of chinook fry observed in the Big Qualicum River, British Columbia. Fry that migrate early as a result of density-dependent factors may be less successful at establishing feeding stations or territories. These fish may remain small and thus subjected to predation for a longer period of time (Larkin 1956).

The implication of competition among juvenile salmonids in an outplanting program is that stocking density and size at release may influence survival of both outplanted cohorts and resident wild fish within the stream. Solazzi et al. (1983) found that outplants of coho fry in several Oregon streams significnatly increased total production but decreased the production of wild juvenile coho by 40% to 50%. The hatchery presmolts were larger than resident coho at the time of release, because of earlier hatching and two to three months of hatchery feeding. Solazzi et al. (1983) attributed the reduction of wild juveniles to a competitive advantage of larger hatchery coho over wild coho for food, space, and cover.

Predictor Models for Estimating Rearing Capacity and Stocking Rate: The production capacity of a stream (biomass per unit area) is dependent upon the total area and quality of habitat available for rearing. Several methods and predictor models have been developed that correlate physical parameters of a stream to biomass of salmonids. These methods of estimating or predicting rearing capacity were developed to provide guidelines for evaluating the suitability of streams for outplanting and appropriate stocking rates.

McIntyre (1983) developed several predictive models, based on data obtained from five populations of spring chinook in the Columbia River basin, as a method of identifying populations that could benefit from outplanting and estimating the minimum number of fish required to increase the populations to levels consistent with the maximum yield of smolts. These models were designed to use information that is often readily available to managers: stream discharge, "carcass" counts, and stream length.

McIntyre (1983) concluded that the hypothetical relationships he developed showed that increased growth and survival at low population density resulted in biomass (total weight) compensation in late summmer if egg deposition was about 90% of the eggs required for full seeding. Although the population does not fully compensate for lower densities, nearly 95% of the carrying capacity biomass in late summer is still attained from egg depositions as low as 75% of the maximum egg deposition.

A more recent model developed by McIntyre (in process) to estimate deficits in the size of spawning stocks of spring chinook in upper Columbia River tributaries uses length of mainstem as an index of the amount of rearing habitat available in a stream and its tributaries. Data from the same rivers used in previous models was used to relate maximum number of smolts produced in each stream to length of the mainstem, rather than stream discharge data used in previous models. Tables were then presented that give estimated deficits in the number of fry in a stream at five levels of natural spawning (percentages of Em, maximum number of eggs deposited) in streams with main-stem lengths from 4 to 235 Km.

McIntyre's methods are the most detailed available, and they use information that is often readily available or simple to obtain. However, this method does not take into account differences in migration patterns of juveniles in the rivers used to generate the equations. McIntyre also assumed that the lowest average monthly stream discharge or the length of mainstem determines carrying capacity, which is influenced by many other variables. In addition, this method does not account for water withdrawals downstream of gauging stations or impoundments, which may not significantly alter discharge but do affect rearing area.

A somewhat simpler method of determining rearing capacity for spring chinook was developed by D.W. Kelley and Associates (1982) in the Tucannon River, Washington. A total of 19.6 miles of stream was surveyed, and rearing habitat for spring chinook was rated as: 1 = poor, 2 = fair, 4 = good, 8 = excellent. They developed a Rearing Index (RI) that equaled RI = (assigned rating times area rated) divided by length of stream rated. Population estimates of salmonids were then conducted in 2 pools, 4 glides, and 4 riffles and plotted against RI values. The resulting equation for rearing habitat could be applied to any rated habitat: rearing capacity (number of fish) = 0.01 + 0.014(RI). The method is a relatively simple way of surveying habitat and estimating rearing capacity in any stream; however, the formula developed was based on sampling only during summer at few sites on one stream. It assumes the stream was fully seeded and that water temperature or other factors were not limiting later in the year.

A similar approach based on a much broader data base was developed by Anderson (1984). Stream habitat was categorized by type (pool, riffle, glide) as described by Bisson et al. (1982). Each type was assigned a range of carrying capacities (density of fish) by species at summer low flow, based on population estimates of salmonids at 365 sample sites in several Oregon coastal streams. Only streams with known steelhead and coho spawning escapements the previous winter were sampled, although no determination of seeding level was made. Anderson (1984) also assumed that fish populations were not limited by unmeasured factors. This method illustrates a range of juvenile steelhead and coho densities in western Oregon streams for different habitat types, but offers limited information on the maximum capacity of each habitat type to rear fish or parameters, including seeding level, that influenced the density of fish found in each habitat type measured.

A set of guidelines for stocking salmonids into Oregon coastal streams was developed by McGie (1985). These guidelines were established to identify populations that could benefit from stocking programs, either through plants of juvenile fish from hatcheries or Oregon Salmon and Trout Enhancement Program egg-boxes, and provide direction on stocking rates consistent with the maximum number of juveniles any particular stream could support. Two approaches to estimating stocking rates were used--one for fall chinook salmon and one for coho salmon, steelhead, and cutthroat trout. For the latter group, the stream considered for stocking was first quantified by types of habitat used by different species (percent pool, gradient, stream order) and by physical characteristics that determine habitat quality (type of cover, channel profile, riparian vegetation, maximum water temperature). These criteria were combined into a habitat quality index (HQI), with the stream placed into one of five categories ranging from "l", indicating poor habitat with little or no potential for rearing, to "5", indicating optimum conditions for the'species throughout the area. Stocking densities were then calculated for each level of HQI, ranging from 0 fish when HQI equals 1, to 4.01 coho/sq m, 1.00 steelhead/sq m, and 1.00 cutthroat trout/sq m when HQI equals 5. Calculations for coho stocking rates came from data in the Oregon Coho Plan (Oregon Department of Fish and Wildlife 1981) and the Alsea River, Oregon (modified from Moring and Lantz 1975). Calculations for steelhead and cutthroat trout were based on stock-recruitment data calculated for summer and winter steelhead races in the North Umpqua River, Oregon, (Oregon Department of iish and Wildlife, unpublished data), British Columbia Stream Enhancement Program guidelines, and from two streams in Idaho (Bjornn 1978; Mabbot 1982). Four stocking models of increasing complexity were presented based on the level of available information on the area of habitat and current spawning population. Recommended fry stocking densities based on the HQI of the stream were then used in each model to calculate the stocking rate, or number of fry to be released into the stream.

Stocking guidelines for fall chinook salmon were based on data obtained from the Nestucca and Siletz rivers, Oregon, which were assumed to be adequately stocked by natural spawning populations at an 'average 0.72 fry/sq m. Potential fry production in each Oregon coastal river was calculated from the ratio of the combined estimated freshwater rearing area in the Nestucca and Siletz rivers (assumed fully seeded) to the estimated rearing area in the river being considered for stocking. Actual fry production in a river system was calculated from an estimate of spawning escapement. The difference between potential and estimated fry production was the number of fry recommended for stocking.

McGie's (1985) method for fall chinook salmon uses the best available information and provides sound guidance for stocking Oregon coastal streams; however, this method may be inappropriate for chinook with different juvenile life histories, particularly spring chinook in the Columbia River basin. Oregon coastal fall chinook typically migrate downstream in their first summer or fall and rear to some degree in estuaries (Herring and Nicholas 1983).

Therefore, juveniles are not limited by over-winter conditions and may not be as influenced by low summer flows and water temperatures as stocks of chinook that rear in freshwater and migrate as yearlings. In systems where the number of wild spawning adults and the area of rearing habitat is known, a modification of McGie's models for estimating coho stocking rate may be applicable to other species. An important variable in these models is the stocking density of fry, which varies according to the HQI of the stream. The maximum fry density at HQI = 5 was calculated from (1) stock-recruitment relationships that predict the number of adult spawners needed to attain maximum sustained production (MSP) in a system and (2) from an estimated egg to smolt survival rate at MSP. In the absence of these data; the desired number of adult spawners and egg-to-smolt survival rate applicable to a particular system would have to be calculated by other methods.

Gamblin (1984) evaluated several habitat-biomass predictor models in an effort to identify and evaluate potential salmonid enhancement projects within the lower Snake River basin. Earlier work with the HQI as described by Binns and Eiserman (1979) indicated that the model did not adequately predict salmonid biomass in anadromous streams in Oregon, Washington, and Idaho possibly because it was developed for Wyoming resident trout streams. To further evaluate the potential of the HQI model and a similar regional model developed by Gamblin (1984), the HQI data base was expanded to identify parameters that might make a habitat-biomass model applicable to salmon and steelhead streams. Stream habitat parameters and salmonid abundance and biomass were measured along 67 study transects in 42 streams within the Salmon, Clearwater, and Lost rivers in Idaho, and in the Wenatchee River in Washington. Results of regression analyses of these parameters indicated that both the refined version of the original HQI model and the regional model did not adequately predict biomass in anadromous streams. Poor performance of the models was attributed to factors that could not be easily measured, yet played a primary role in stream biomass variation--seeding level by anadromous species, straying of presmolts (particularly steelhead) into nonnatal streams after over-wintering in larger streams, and the effect of angling mortality on biomass in the study streams. Gamblin (1984) concluded that a predictive model for anadromous fish stream production was not realistically attainable at this time, and that the best method to evaluate habitat quality or guide hatchery outplanting programs continues to be a skilled professional opinion, based on the best available data.

Summary and Conclusions: The suggestions and guidelines for outplanting that follow were located in the literature.

The Stream Enhancement Research Committee (1980) says:

> Mature adult salmonids can be transferred directly upon capture to the areas of stream above an obstruction. This method of initiating the colonization of an area has been used successfully, however, there have also been instances where some of the transferred stock has dropped back downstream to spawn in the area from which they were captured.

Phinney (1965) made the following recommendations as the result of cost:benefit analysis of a coho lake rearing project:

1. Streams selected for stocking should be under-seeded due to either (a) low escapements or (b) lack of spawning area.

2. In years of high escapement, stocking should be reduced to include only areas which are chronically under-seeded because they lack sufficient spawning area.

3. Where conflict with existing populations is likely, fry plants should be designed to minimize the size differences between stocked and wild fry.

Bjornn (1978) reported that spring chinook fingerlings had to be planted into Big Springs Creek adn the Lemhi River, Idaho, in late May for fish to remain in the streams. He also cautioned that:

1. Broodstock used for supplementation should be as genetically similar to native, naturally spawning populations as possible. If there are not native fish in the stream, broodstock should be taken from closely adjoining streams.

2. Careful consideration should be given to the timing of introducing supplemental fish into the streams.

We believe that the following considerations are important in any outplant Program:

1. In wild fish only streams enhancement is best accomplished by habitat protection and harvest control. Where fishery managers are primarily concerned about maintenance of genetic integrity of wild stocks, supplementation with hatchery stocks should not be considered.

2. Many of our anadromous fish streams are managed for wild-hatchery mix, with the decision usually justified by the intention to take substantial care to minimize interactions between the wild and domesticated stocks. Adding hatchery fish to stream areas to supplement wild rearing without substantially affecting the wild stocks, while theoretically possible, may be impractical given the biological, technical, and political difficulties involved. Without respect to proven effectiveness, the following considerations have been practiced or suggested to minimize wild-hatchery interactions and to improve potential for success of an outplanting program:

   a. Stocks for introduction should be derived from or closely related to the wild stocks in the stream.

b. The carrying capacity of the receiving water should be evaluated, and only sufficient outplant fish should be introduced to make effective use of underseeded habitats. When carrying capacity is in doubt, deliberately understock.

c. Theoretically, the method of introducing hatchery fish can have a material effect on the hatchery-wild interaction potential (personal communication during August 1985 with J.D. McIntyre and R.R. Reisenbichler, U.S. Fish and Wildlife Service, Seattle, Washington). Introduction methods that minimize possiblity for artificial selection should be preferred.

1) Introductions of locally-adapted adults appear to minimize interaction potential, assuming reasonable stocking rates.

2) Introductions of locally-adapted smolts will yield eventual adult returns, but smolt quality must be good, or in-stream residualism of planted smolts provides competition and predation.

3) Introductions of locally-adapted eggs (Vibert Boxes or streamside incubators) are somewhat questionable in relation to numbers of unfed fry that survive to emerge. Previous thermal history of the eggs must be considered.

4) Unfed fry and presmolts from hatcheries appear to have the highest potential for harmful interactions with wild fish.

d. Introductions of the various life stages can be coordinated to minimize impacts: supplemental fish or eggs can be released at sizes, temperature units, et cetera comparable to the existing wild population.

e. The genetic quality of hatchery fish for outplanting can be maintained to a degree through rigorous use of good spawning and propagation practices (take eggs throughout the duration of the run, use proper sex ratios in the spawning process, spawn all age classes and sizes of returning adults, et cetera). Some fish culture programs mark all hatchery-released fish to permit identification of hatchery and wild fish when adults return to the hatchery weir. Some known wild fish can then be purposely spawned as a means of infusing wild genes back into the hatchery stock. However, almost all these precautions require extra forethought, work, and care, which limits expediency. Some enlightened programs will go to the extra effort to insure the genetic intregity of the hatchery stock, but 53% of the hatchery experts questioned in a recent survey[1] responded that human efficiency, not resource concerns, is the primary basis of fish culture decisions.

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1 Diggs, D.H. 1984. A "Delphi" survey into the methods and practices of spring chinook salmon culture. United States fish and Wildlife Service, Dworshak Fisheries Assistance Office, ahsahka, Idaho, USA.

3. In streams managed exclusively for hatchery production, supplementation plans are reasonably easy. Advanced presmolts can be released late enough to avoid population-reducing effects of freshets; and if quick adult returns are desired, smolts can be released.

Recommendations: We recommend a study of outplant programs as a way of returning still-habitable stream areas back to producton of anadromous fish. We have seen that changes in juvenile rearing densities do not necessarily reflect subsequent adult return; thus we recommend that any outplant program be evaluated in terms of adult return and, where practical, into second generation effects.

The attached Willamette Supplementation Study proposal appears to provide many of the desirable attributes for outplant evaluation (use of indigenous stocks, evaluation of adult return, and concentration on a critical species). However, availability of test streams limits the potential number of treatments that can be tested.

Assuming acceptable stocks and stream numbers can be obtained, outplant tests with coho should be considered in order to take advantage of the potential benefits of comparing results between species and the more efficient data collection benefits provided by the shorter life cycle of the coho.

Tasks 1.12 and 1.15

The purpose of these tasks is to estimate potential benefits and adult return from offstation release of hatchery-reared smolts. This question is complicated by the extreme variability of observed survival rates between releases of smolts, by the expected spawning success of those adults that survive to return, and by the viability of the progeny that may result from such spawning.

Adult return rates from hatchery-released smolts in the Willamette system have ranged from 0% to 1%, depending on brood year and hatchery of rearing and release (Table 4). In an attempt to generalize, we estimate that an "average" group of spring chinook smolts from a "typical" Willamette River hatchery would return 2.9 adults to the stream of release from 1,000 smolts liberated. Adult returns are infrequently typical; some facilities are consistently more efficient than others. In reality the number of adults that return from a given smolt release depends on many factors including hatchery regime, disease history, prerelease handling, duration of transportation of smolts, and vagaries of ocean environment and fishing presssure.

Another concern is whether adults that return from hatchery-released smolts will survive to spawn. Such adults can spawn, assuming environmental conditions for adult survival to time of spawning are present, but at a lower level than would be expected from similar numbers of naturally-produced adults (Solazzi et al., in process; Chilcote et al, 1984). The survivability of progeny thus produced is also questionable. Based on the volume of data related to inferior genetic makeup of hatchery fish and the long history of domestication of Willamette chinook stocks, we suspect continued smolt releases would be required to maintain a 1:l ratio of parent to progeny return to most Willamette River tributaries.

Table 4. Percentage survival rates for Ad + CWT marked smolt releases, Willamette spring chinook hatcheries.

Hatchery, brood, time of release	Percent survival from smolts released: Total survival	Return to hatchery
Oakridge-Dexter		
1974:		
Fall	2.41	0.79
Spring	1.06	0.30
1975:		
Fall	0.62	0.21
Spring	0.29	0.07
1977:		
Fall	1.47	0.67
Spring	2.06	0.47
1978:		
Fall		1.07
Spring		0.68
1979:		
Fall		0.32
Spring		0.81
Marion Forks		
1974:		
Fall		0.00
Spring		0.00
1975:		
Fall		0.00
Spring		0.03
1976 spring:		0.01
1977 spring:		0.17
1979 spring:		0.10
South Santiam		
1975:		
Fall	0.76	0.34
Spring	0.15	0.05
1976:		
Fall	0.97	0.46
Spring	1.24	0.43
1977:		
Fall	0.34	0.14
Spring	0.37	0.07
1978:		
Fall		0.05
Spring		0.06
McKenzie		
1978:		
Fall		0.24
Spring		0.01
1979:		
Fall		0.08
Spring		0.26

Smolts can be defined as immature anadromous fish at a stage of development where they are ready to migrate to the sea. Current hatchery practices strive to produce a smolt that will begin seaward migration immediately after release. Thus, smolt releases provide the potential for making use of underseeded stream areas only after time has elapsed, adults have returned and have produced viable progeny. We believe some Willamette Basin streams lack suitable conditions for oversummer holding of returning adults, but still could rear juvenile salmon. In these streams, release of smolted juveniles never would take advantage of the unused rearing capacity.

<u>Reference for Tasks 1.12 and 1.15</u>: Chilcote, M.W., S.A. Leider, and J.J. Loch. 1984. Kalama River salmonid studies. Washington State GameDepartment, Fisheries Management Division 84-5, Olympia, Washington, U.S.A.

Task 1.13

The purpose of this task is to identify reservoirs and streams in the Willamette basin that are currently underseeded with spring chinook.

<u>Rearing Potential Rearing Salmon in Reservoirs</u>: Juvenile spring chinook are well adapted to rearing in Willamette Valley reservoirs (Korn and Smith 1971), and three large reservoirs in the basin currently rear salmon as part of an annual production program. Requirements for successful rearing and juvenile passage from reservoirs that do not produce power are reasonably well established (Smith 1976). A suitable downstream-migrant collection system was developed (Wagner and Ingram 1973) about the time the last hydroelectric-generating storage reservoir was constructed on a major Willamette Basin tributary.

Large hydroelectric projects now block major portions of the historical spawning and rearing areas for Willamette spring chinook. The production potential of areas above these dams is largely intact, but reestablishment of salmon populations is precluded by lack of effective passage facilities for downstream migrants. However, turbine-inflicted mortality rates that restrict maintenance of wild populations of salmon may be acceptable when put in the perspective of offstation releases of excess hatchery stocks of fish to supplement existing production.

Although impounded waters and their tributaries in the Willamette basin provide substantial potential for rearing salmon, several factors often preclude establishment of effective supplementation programs:

1. Most dams with turbines lack effective juvenile passage facilities, and the cost of retrofitting is often prohibitive.

2. Populations of competitive and predatory fish often limit or eliminate production potential. Juvenile salmon compete well with most other indigenous salmonids. However, introductions of warmwater fish species, frequently illegal, have had devastating effects on survival of young salmon in reservoirs.

3. Fishery managers are sometimes hesitant to rear salmon because of potential interference with established fisheries programs.

4. Lack of manpower to more intensively manage existing reservoir-rearing programs.

Major impounded waters in the Willamette basin and pertinent salmon-rearing data for each are as follows:

1. Clackamas River System. The River Mill, Faraday, North Fork Reservoir complex - marginal adult passage. Smolts that migrate at periods of no spill are passed around these projects via the North Fork "skimmer" (Figure 2). During spill periods, many smolts pass over North Fork Dam into Faraday Reservoir and power canal or into River Mill Reservoir, resulting in high mortality. Chinook presmolts and smolts are currently released into stream areas above these dams, and substantial natural spawning sometimes occurs. Portland General Electric Company mitigates losses of chinook at these projects with smolt production at Clackamas Hatchery.

2. Santiam River System. Substantial potential for rearing salmon exists in Detroit Reservoir and tributaries above Detroit Dam on the North Santiam River. Turbines currently reduce survival of migrants. Detroit Reservoir is managed for a trout fishery. Salmon losses are mitigated by a United States Army Corps of Engineers funded hatchery at Marion Forks.

A once substantial rearing program (two million presmolts per year) in Green Peter Reservoir and tributaries on the South Santiam River now appears limited by predacious fish, negating the utility of successful downstream migrant facilities. Foster Reservoir has limited rearing potential because of large populations of nongame fish,and because smolts passing through Foster Dam turbines sustain 15% to 20% mortality (Wagner and Ingram 1973). Losses of salmon and steelhead production in flooded areas are mitigated by United States Army Corps of Engineers funded South Santiam Hatchery. Migrant-protection studies are being conducted.

3. McKenzie River System. Leaburg Lake currently rears naturally-produced chinook and some presmolts are released into tributaries. Leaburg Dam diverts the majority of migrating smolts through a canal into a turbine that kills many fish (Smith et al. 1982). A fish-protection screen has been installed at the diversion to eliminate this source of mortality.

Blue River Reservoir currently rears 200,000 presmolt chinook annually. Additional rearing capability exists, but chinook rearing must be balanced with a trout fishery. Although there are no turbines on the reservoir discharge, migration is effected by release of water through low-level regulating outlets.

Cougar Reservoir has excellent potential for rearing chinook, and major spawning and rearing areas exist above the reservoir. A juvenile passage system installed when the dam was constructed was evaluated and found ineffective (Ingram and Korn 1969). Cougar is a high-head hydropower dam with low-level turbine intakes. Retrofitting for a temperature-control structure, which is currently being investigated (USACE 1984), may, if constructed,

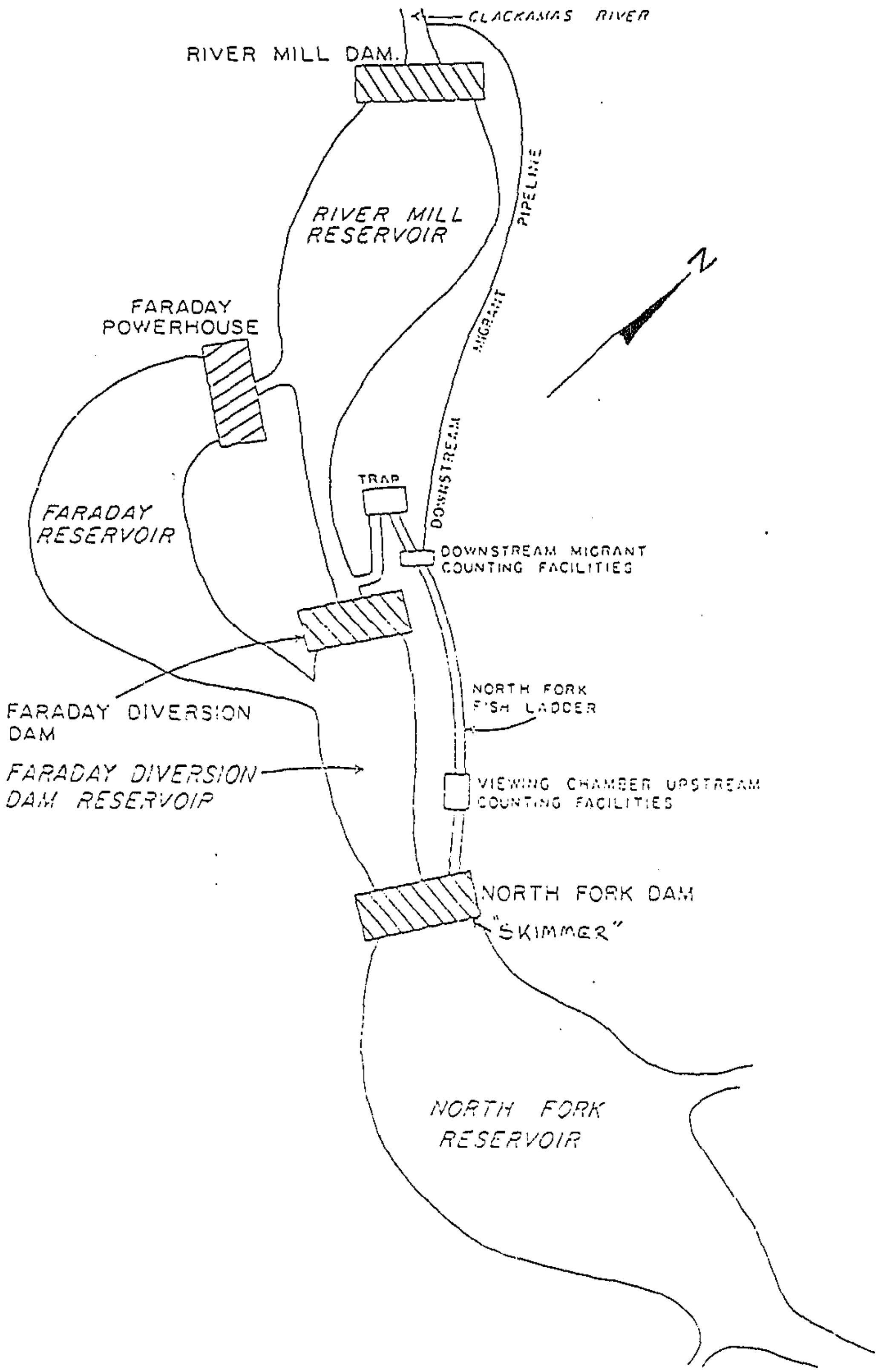

Figure 2. Sketch of mid-Clackamas hydroelectric developments.

provide migrant-passage benefits. Currently managed for trout. Salmon losses because of the project are mitigated by United States Army Corps of Engineers funded McKenzie Hatchery.

EWEB's upper McKenzie hydro complex: Trail Bridge Reservoir appears to be the only project among this complex practical for consideration of reservoir rearing of spring chinook. Major considerations for use of this reservoir in salmon rearing efforts are:

1. One hundred and twentv surface acres of relativelv infertile, but good quality, water at full pool.

2. Predaceous and competitive fish in the reservoir are limited to salmonids.

3. Normally no spill at existing operating conditions.

4. Chinook must sound 40 feet to the top of the turbine intake structures to migrate.

5. Migrants would have to pass through a Kaplan turbin under 90 feet of head to leave the reservoir. Based on ODFW experience at other Willamette Valley projects (Smith 1976), we would expect to release 60,000 spring chinook fingerlings into Trail Bridge Reservoir in June of each year, and 15% (9,000) would survive to migration. Assuming all surviving smolts found the intake, approximately 10%[1] (900) would die passing through the Kaplan turbines. Of the remaining 8,100 smolts 2% (160 adults) would survive and return to the project, assuming adequate protection during emigration. This estimated survival to return would provide approximately the same annual levels of adult entry as the largest previous counts into Carmen-Smith spawning channel (Figure 5), as well as yield about 125 adults to freshwater fisheries and 149 adults to offshore fisheries (based on mean catch to escapement levels observed in Table 6).

4. Coast Fork Willamette River System. In-reservoir rearing of salmon in Cottage Grove Reservoir was studied from 1969 to 1975. Cottage Grove Reservoir produced up to 345,000 spring chinook smolts per year, but large populations of warmwater game fish required frequent treatment with rotenone to maintain high levels of salmon survival. The dam does not have any turbines on its low-level regulating outlets. The reservoir is currently managed for warmwater game fish and trout.

Dorena Reservoir has essentially the same physical features as Cottage Grove Reservoir. Salmon production potential depends on control of predaceous species in the reservoir. This reservoir is currently managed for warmwater game fish and trout.

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1 Estimated 13% mortality to chinook smolts released into Kaplan turbines with 90 feet head at Walterville powerhouse (Smith et al. 1982) and a generalized 7% Loss for Kaplan turbines examined by Bell et al. 1957.

5. Middle Fork Willamette River System. Fall Creek Reservoir has reared juvenile spring chinook each year since 1965. No turbines exist on its low-level regulating outlets. Juvenile evacuation and a degree of rough fish control are accomplished by complete draining of the reservoir each fall. The rearing program targets release of 1,000,000 presmolt (100-500/lb) spring chinook into the reservoir annually. Fingerling-to-smolt survival was measured at 13.5% in 1974 and 11.3% in 1975. Adult returns to the project since 1969 have ranged from 4,696 to 136, with a mean annual return of 1,546. The reservoir is managed for spring chinook rearing and a put-and-take trout fishery. For the two broods for which we have accurate reservoir-reared smolt migration estimates, adult return to the project averaged over 2%, about twice the survival to return we observe from our best hatchery-reared smolts.

Lookout Point is a high-head hydropower dam with low-level turbine intakes. It impounds a large deep reservoir that is heavily populated with nongame fish and a few warmwater species. Spring chinook released in this reservoir appear to survive at a low level, and we have observed that some migrate through the turbines. Dexter Reservoir, Lookout Point Dam's reregulating facility, generates low head power and spills with some frequency. Large populations of nongame fish limit potential for in-reservoir rearing. Losses of salmon rearing area blocked by Lookout Point and Dexter reservoirs are mitigated by USACE-funded Oakridge-Dexter Hatchery complex.

Potential for Rearing Salmon in Streams: The potential, for rearing coho salmon in most stream areas of the Willamette Drainage has been estimated based on stream surface area and 0.42 smolts/yd^2 (Williams, in process). Larqer streams suitable for rearing spring chinook do not appear in these estimates.

We asked each district fishery management biologist in the Willamette basin to identify those streams within his jurisdiction that met the following criteria:

1. Spring chinook populations currently reduced from historic or desirable levels.

2. Habitat suitable to rear juvenile spring chinook.

3. Stream size to permit evaluation.

4. Management guidelines compatible with our proposed Supplementation Study (capable of receiving unfed fry, 100-500/lb presmolts, or gravid adults).

We also asked these managers to empirically estimate the desired mean annual levels of adult return to each of these currently-underseeded streams. The distribution of identified streams appears in Figure 3, and descriptions of habitat quality appear in U.S. Fish and Wildlife Service (1940), Willis et al. (1960), and the Willamette Basin Comprehensive Study (Willamette Basin Task Force 1969).

The features of each stream are listed under the management district in which they are located.

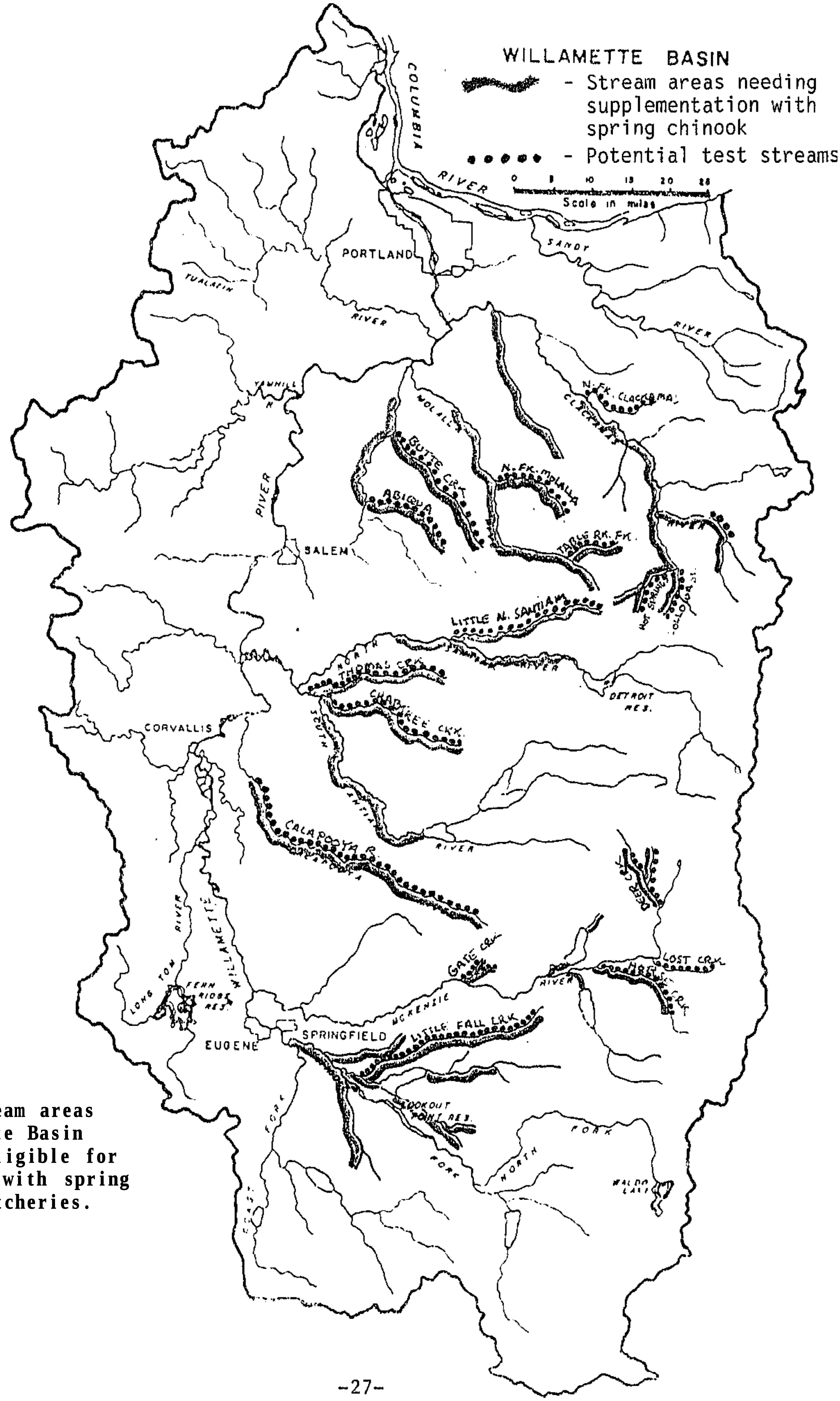

Figure 3. Stream areas in the Willamette Basin identified as eligible for supplementation with spring chinook from hatcheries.

1. Lower Willamette District Streams. Salmon produced in these stream areas are subject to mortality during migration past PGE's dam complex in the mid-Clackamas River area.

The Collowash River provides good habitat for adults and fair potential for juvenile rearing. It currently supports a variable but low adult return. The desired annual escapement is 300 adults.

Hot Springs Fork of the Clackamas River provides good habitat potential for adult and juvenile chinook, currently with a low adult escapement. The desired escapement is 200 adults.

The Big Bottom area of the Clackamas River contains excellent habitat for adults and juveniles. Low adult escapements are currently supplemented by adults trucked from the North Fork Dam adult trap. The desired annual escapement is 1,500 adults.

The North Fork Clackamas River contains fair habitat for adults and juveniles, and existing low adult populations may adequately seed the rearing area. It probably supports about 50 adults currently. This stream is deemed suitable for a control stream.

2. West Slope-Molalla District Streams. Table Rock Fork Molalla River has habitat that is suitable for juvenile rearing but is questionable for adult holding. A snorkel survey in 1984 located 39 adults that resulted from a release of smolts in 1981. The desired annual escapement is 100 adults.

Habitat in the North Fork Molalla River is suitable for juvenile rearing, but only marginal for adult holding. A snorkel survey in 1984 detected only 2 adults. The desired annual escapement is 100 adults.

Butte Creek may adequately rear juveniles but has poor habitat for adult holding; thus, this stream is most suitable for fry or presmolt releases. No adults currently use this stream. The desired annual escapement is 30 adults.

3. Mid-Valley District. Abiqua Creek once supported spring chinook, but is now devoid of this species. Habitat could rear juveniles, but adult holding water is limited. The desired annual return is 300 adults.

Thomas Creek has fair potential for juveniles and adults. A few adults still spawn in this system. The desired annual escapement is 300 adults.

Crabtree Creek has fair potential for juveniles and adults. The desired annual escapement is 300 adults.

The Calapooia River once supported a chinook population that declined because of chronic adult-passage problems at diversion dams. It still has good potential for juvenile rearing and good habitat for adult holding in the upper river area. The desired annual escapement is 400 adults.

The Little North Fork Santiam River has good habitat for juveniles and adults, although holding pools for adults are limited. Adults still spawn in this stream. The large size of this stream may limit adequate evaluation. The desired annual escapement is 400 adults.

4. Upper Willamette District. Horse Creek contains good water quality and quantity for juveniles and adults, although rearing pool area may limit smolt production. A few salmon still spawn in this stream. The desired annual escapement is 400 adults.

Lost Creek has good water quality for juveniles and adults. Adult returns are much reduced over historic levels, but salmon still return and spawn. The desired escapement is 600 adults, but the management preference would be to maintain this as a control stream.

Deer Creek is marginal for juveniles, and the quantity of water is poor for holding adults. The desired escapement is 50 adults.

Gate Creek could rear juveniles and adult holding water is of fair quality. Some adults spawned in the lower sections in recent years. The desired annual escapement is 200 adults.

Little Fall Creek likely could rear some juveniles,but has poor midsummer volume for holding adults. A block to the upstream migration of adults is being laddered. The desired escapement is 75 adults.

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Task 1.14

The purpose of this task is to identify criteria for selection of hatchery stocks to use. Guidelines for introduction of fish species and stocks to release in Oregon waters are generally established by the following policy documents:

1. Fish Stocking Policy for Oregon (ODFW 1974). This paper defines species and races of fish cleared for introduction into Oregon waters, discusses disease introduction safeguards, and prescribes procedures for submitting requests.

2. Wild Fish Management Policy (ODFW 1980a). This policy formally recognizes the importance of natural selection and genetic identity of wild fish, and it ranks three levels (wild fish only, wild-hatchery mix, hatchery fish only) of fish management options to be applied to each water body in Oregon.

3. A Departmental Guide for Introduction and Transfers of Finfish into Oregon Waters (ODFW 1982). This guide describes specific locations within the state where introductions of exogenous fish are permitted.

4. Willamette Basin Fish Management Plan (ODFW 1980b). This plan provides goals, guidelines, and needs for the management of important fish species and aquatic organisms in the Willamette basin.

Within the confines of these written guidelines, individual fishery biologists have the freedom to choose the stocks to use within their geographic district. Decisions about stocks to use in a specific stream are influenced by economic, biological, genetic, and social considerations. A discussion of these influences is being drafted in "Management Concepts of the Comprehensive Plan for Production and Management of Oregon's Anadromous Salmon and Trout" (ODFW, in process).

A synthesis of these considerations in relation to the application of offstation salmon releases in the Willamette basin to supplement wild rearing would conclude:

1. Only "Willamette stock" spring chinook collected at Willamette basin facilities may be used in supplementation efforts in the Willamette system.

2. To the degree practicable, subbasins will be isolated. For example, excess hatchery fish collected on the South Santiam River at Foster Dam will be used in supplementation efforts in the South Santiam subbasin, excess fish or eqgs from Minto Pond on the North Santiam River will be used in the North Santiam subbasin, et cetera.

3. Cross transfers between subbasins will be discouraged, but may be permitted in those subbasins that have historically exchanged fish or spawn with some frequency (Table 5). However, the long-term goal of the fishery managers is to eliminate subbasin cross transfers of "strains" of the Willamette stock spring chinook.

Table 5. Potential for future cross transfers of "strains" of spring chinook between subbasinsa of the Willamette River drainage based on records of past transfers of fish and spawn.

Donor stream	Receiver streams[a] Clackamas	North Santiam	South Santiam	Middle fork Willamette
Clackamas				X
North Santiam	X		X	
South Santiam		X		
McKenzie				X
M. Fk. Willamette	X	X	X	

a Although the McKenzie subbasin has often received fish and spawn from other stations, current policy is to release only McKenzie stock spring chinook back into the McKenzie drainage.

4. Only McKenzie stock spring chinook may be released into the McKenzie River.

5. The only exogenous stock of spring chinook currently cleared for introduction into the Willamette basin is the Carson (Wind River, Washington) spring chinook for use in the Coast Fork Willamette, in Fall Creek (Middle Fork Willamette tributary), and in the North Santiam River only. While several broods of Carson stock chinook were experimentally released in to the basin, none have been used since the 1980 brood, and no further releases are anticipated.

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Oregon Department of Fish and Wildlife. Drafted, in process. Management Concepts of the Comprehensive Plan for Production and Management of Oregon's Anadromous Salmon and Trout. Part 1. General considerations. Portland, Oregon, USA.

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Task 1.16

The purpose of this task is to provide an evaluation of Carmen-Smith spawning channel. The spawning channel concept was a favorite of many fishery agencies and hydropower developers in the 1960s. Theoretically, these channels would take care of themselves and would provide holding, spawning, and rearing areas in a seminatural environment. Several channels of varying sizes were constructed throughout the Western United States, British Columbia, and Alaska. Many of the larger channels in the main stem of the Columbia River that were designed to support chinook, coho, and steelhead were later converted into hatchery-supplementation facilities (CH_2M Hill 1978). Reasons for the general failure of large channels to automatically provide the desired production appeared to center around problems with fish behavior (general lack of "unique hydrological character" of the channels) and with suboptimal water temperatures and diseases, which were often aggravated by the flow-through serial design of the channels (personal communication during June 1984 with V.W. Kaczynski, CH_2M Hill, Corvallis, Oregon).

Eugene Water and Electric Board (EWEB) built Carmen-Smith spawning channel in 1960 to replace spawning areas lost through construction of Trail Bridge Dam on the upper McKenzie River. This 500-foot-long, 30-foot-wide artificial channel was designed to accomodate spawning of about 200 adult spring chinook salmon (Figure 4).

Since its first use in 1961, peak count of chinook in the Carmen-Smith Channel has been 169 adults in 1961 and in 1964 (Hagey 1968). Over time, adult entry into the channel has declined progressively, apparently related to declining salmon escapements into the upper McKenzie River (Figure 5). Because only about one to two percent of the annual Leaburg Dam escapements of spring chinook enter the Carmen-Smith Channel, the decline of upper McKenzie chinook runs cannot be blamed on the failure of this facility.

For the relatively few chinook that reach Trail Bridge Dam, Carmen-Smith spawning channel appears to provide an acceptable holding and spawning area. From 1961 to 1970, fry-to-egg survival averaged 30.7%. Several year classes of emergent fry were fin-clipped as they left the channel, and a few of these marked fish returned as adults in subsequent years (EWEB, unpublished data). Although the existing spawning channel provides some public relations benefits to EWEB, we have no data to indicate that natural holding and spawning areas are limited in the McKenzie River above Leaburg Dam.

Potential for use of the Carmen-Smith Spawning Channel in Conjunction with Hatchery Operations: EWEB's upper McKenzie channel provides a seminatural stream with controlled year round flow of 80-90 cfs of good quality water. With some modifications of facilities and operations, these physical circumstances provide several potentials for integration of use of hatchery-excess salmonids:

1. Eggs could be introduced via Vibert boxes or hatchboxes to supplement the existing low levels of natural spawning. The fry-trapping capability at the downstream end of the channel could be used to monitor success of emergence.

2. Unfed fry could be released, but the natural rearing potential in the channel proper is limited.

3. Presmolts could be released and with the addition of appropriate screening and money for feeding, presmolts (fingerlings) could be retained in the channel and fed to smolts as a hatchery-rearing program in a semi-natural environment.

4. Smolts could be released and, with appropriate screening, the channel could be used as an acclimation facility.

5. Adults could be held for spawning. With provision of appropriate screening and watchmen, early transport of hatchery-excess adults could be made without danger of post-release fallback. Fallback of spring chinook adults before they are ready to spawn has been an observed in previous adult-transport operations in the basin. Quality of water in the spawning channel appears excellent for holding of adults during the critical June through October period. Security provisions for held adults would be mandatory.

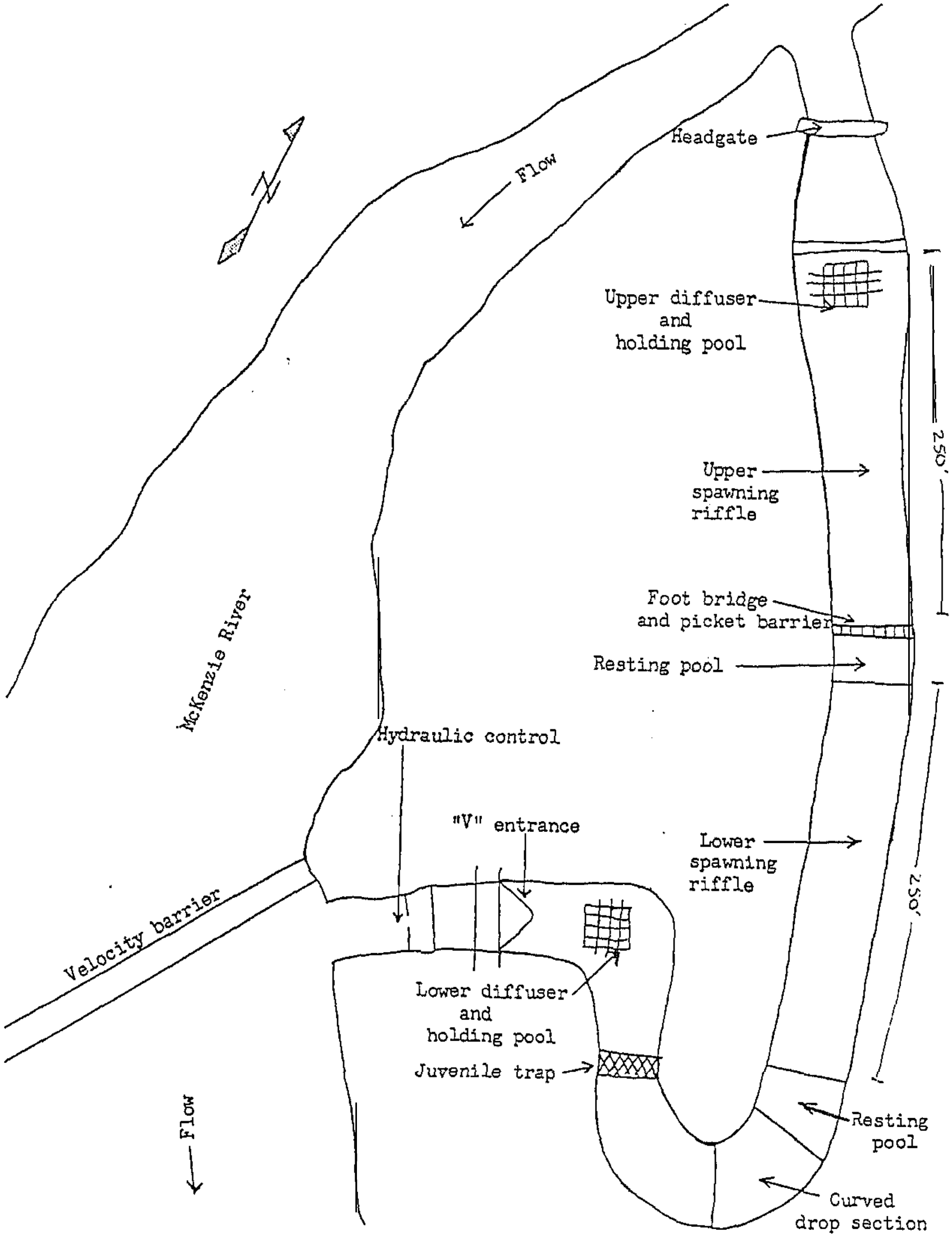

Figure 4. Schematic drawing of Camen-Smith spawning channel

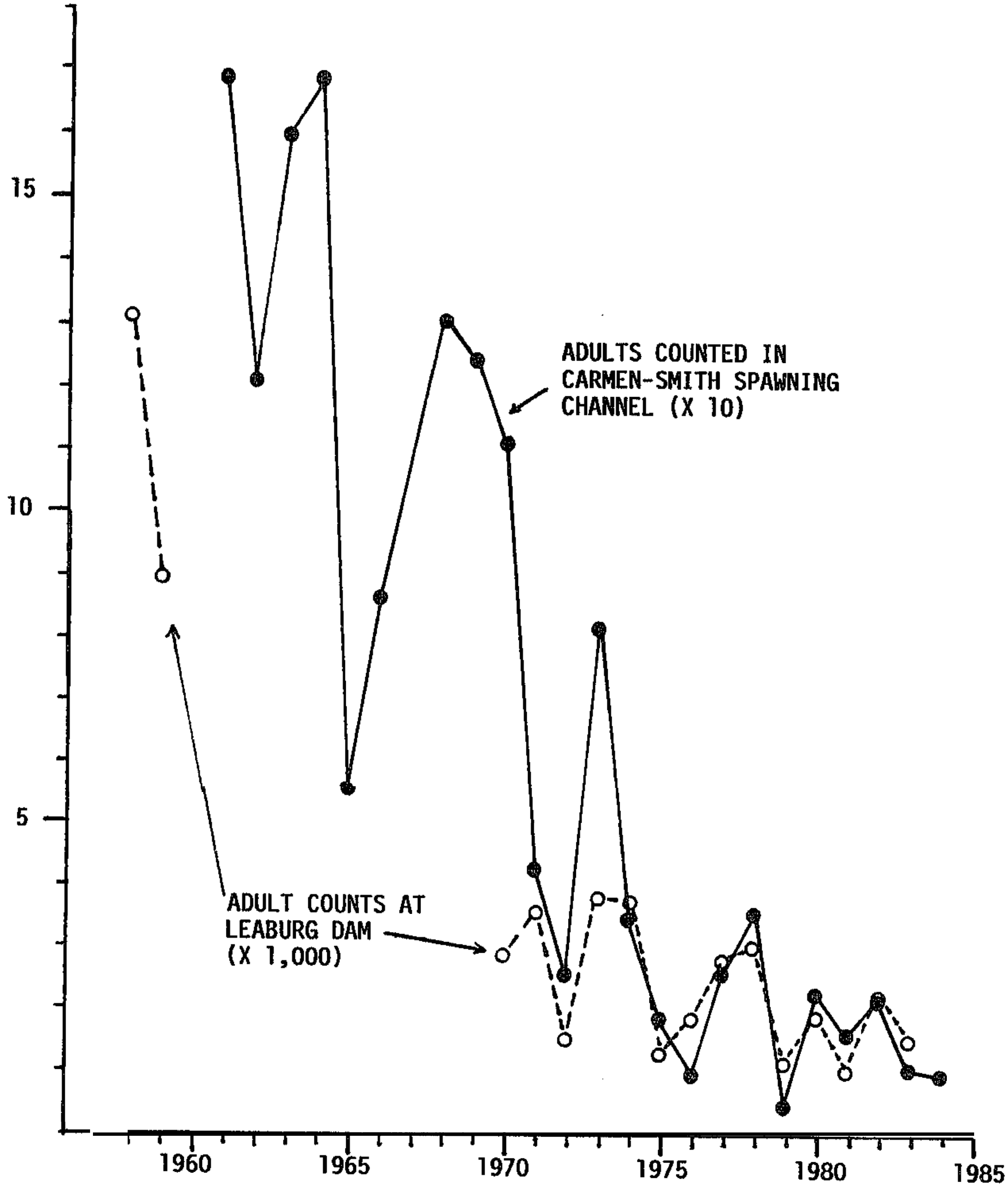

Figure 5. Adult counts at Leaburg Dam and Carmen-Smith spawning channel for years of record, 1958-1984.

References far Task 1:16:

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Task 1.17

The purpose of this task is to examine existing harvest of Willamette River spring chinook.

The best information regarding survival and harvest of hatchery-released spring chinook smolts from Willamette River facilities has followed use of coded-wire tags beginning in the mid-1970s. Since the.inception, sampling of offshore catch for wire-tagged salmon has been much more systematic, and opportunities for duplicated marks or missed marks during sampling has been much reduced.

Based on Ad + CWT recoveries for completed broods of representative test smolts from two Willamette chinook hatcheries, we saw substantial between-brood variations in catch-to-escapement rates (Table 6). On the average, it appears that Willamette spring chinook smolts will yield about two adults to fisheries (catch) for each adult that returns to the hatchery (escapement). Further, it appears that the typical brood might provide adults in three approximately-equal parts: one-third to saltwater harvest, one-third to freshwater harvest, and one-third to escapement.

Table 6. Estimated recovery rates of representative groups of coded-wire tagged spring chinook released from Willamette River hatcheries, 1974 to 1977 broods.

Brood	Hatchery	% Saltwater fisheries	% Freshwater fisheries	% Hatchery return
1974	Oakridge-Dexter	23.1	44.0	32.9
1974	Oakridge-Dexter	35.2	36.7	28.1
1975	Oakridge-Dexter	29.3	36.9	33.8
1975	Oakridge-Dexter	17.6	29.4	52.9
1975	South Santiam	27.6	27.6	44.7
1975	South Santiam	29.7	39.3	31.0
1976	South Santiam	34.5	18.2	47.3
1976	South Santiam	47.1	18.4	34.5
1977	South Santiam	34.7	25.1	40.2
1977	South Santiam	49.3	31.7	19.0
1977	Oakridge-Dexter	28.6	26.0	45.4
1977	Oakridge-Dexter	26.2	26.5	47.3
Average over broods examined		32.5	29.6[a]	37.8
Observed range		17.6-49.3	18.2-44.0	19.0-52.9

[a] *Lacks above-falls sport harvest data, thus this is a minimum estimated freshwater fishery rate.*

Willamette spring chinook are harvested in saltwater primarily north of Oregon and in freshwater primarily in the lower Willamette River sport fishery (Figure 6). Canadian fishermen take the majority of the saltwater catch. Very few Willamette chinook are caught offshore of California or Oregon.

Objective 1.2

The second objective of this study was to identify methodology and requirements for evaluation of test results.

Task 1.21

The purpose of this task is to describe experimental design.

The number of available test streams in the Willamette basin limits evaluation of all desired stocking methods and densities. Thus, we will attempt to level the densities of stocking, and limit stocking treatments to those that might be most useful. Egg hatchboxes, which are considered a stocking treatment, will not be evaluated. Salmon and Trout Enhancement Program (STEP) experience indicates that, barring unforeseen water supply problems, spring chinook hatchboxes in the Willamette Basin produce 80% survival from green eggs to emergent fry (personal communication during June 1985 with Richard L. Berry, Oregon Department of Fish and Wildlife, Portland, Oregon).

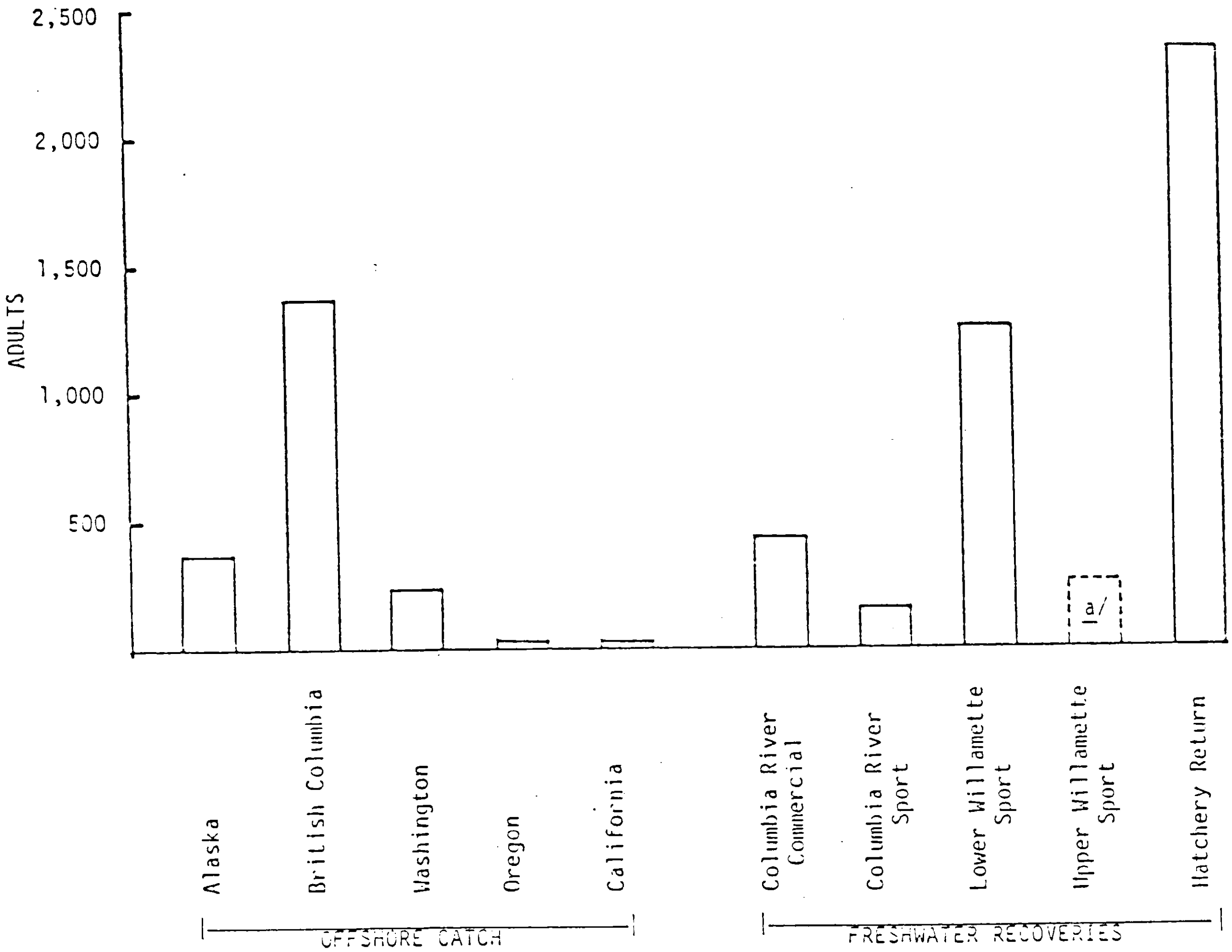

Figure 6. Distribution of recovery of 6,270 coded-wire tagged spring chinook from Oakridge-Dexter and South Santiam hatcheries, 1974-1977 broods.

a/ Upper Willamette sport fisheries are not intensively monitored. We estimated this recovery based on mean annual percentage of reported above-falls catch (from punchcards) in relation to below-falls harvest.

Smolt releases were also considered as a stocking treatment. Limitations of smolt releases in exploiting underseeded habitats and estimates of adult return from typical smolt releases appear in Task 1.12, page 34.

Fishery managers have identified 16 streams in the Willamette basin that are suitable for evaluation. We will use these streams to establish a randomized block analysis design (Snedecor and Cochran 1967), grouping the 16 streams into four blocks according to their estimated productivity potential (Table 7). Each of the four streams within each block will receive a random treatment for evaluation. Treatments will be (1) gravid adult salmon, (2) swimup fry from hatcheries, (3) 100-500/lb short-fed presmolts, and (4) an unstocked control stream. To level density effects, each treatment stream will be stocked with approxmately equivalent units of adult salmon, unfed fry, or presmolts from hatcheries. The first target densities will be based upon the empirical productivity estimates for adult return provided by the district fish biologists; however, rates of stocking will be adjusted by stream after the first year of adult counts becomes available. The goal will be to make effective use of available rearing productivity without overstocking.

Task 1.22

The purpose of this task is to estimate sampling effort required to assure adequate sensitivity of statistical analyses.

Rearing density of juveniles is not an accurate predictor of adult return (Solazzi et al. 1983). Fortunately, Willamette spring chinook can be inventoried as adults in the streams of return, but this requires long-term sampling, because each brood returns over a 5-year span.

Test streams will be stocked for four consecutive brood years (1986 through 1989 broods). All treatment and control streams will be surveyed for adults twice each year from 1986 through 1995 (Table 8). During the first survey, which will be conducted from 15 July to 15 August each year, we will count adults. During the second annual survey, which will be conducted from 15 September to 15 October, we will count redds and collect scales or vertebral centra to determine age class of spawners. Because full-sized adults will not return from the 1986-brood stocking until 1990, stream surveys conducted from 1986 to 1989 will provide baseline adult return data for comparison purposes. Annual surveys of the four control streams will provide similar data, and we can also compare adult return among the different types of treatment streams. Differences in adult return among the treatments tested will be determined by analysis of covariance, an approach recommended for comparative types of study (Anderson et al. 1980). We will make use of environmental data (total run size, escapements at dams, river conditions, et.cetera) along with baseline adult densities (control stream counts, baseline adult counts collected in 1986-1989) as covariates in the analyses.

Using methodology developed by Lichatowich and Cramer (1976), we developed sensitivity curves that indicate we can detect minimum differences of from 50% to 100% of the overall mean numbers of adult chinook in the test streams (Figure 7). However, use of covariates to help explain

Table 7. Willamette basin test streams with pertinent data.

Stream	Production class	Estimated adult potential	Maximum annual stock density[a]			
			Fry	Presmolt	Adult	Control
Little Fall Creek	Low	75			45	
Deer Creek	Low	50		46,000		
Butte Creek	Low	80	134,000			
N. Fork Clackamas[b]	Low	50				X
Hot Springs Fk Clackamas[b]	Moderate	200				X
Table Rock Fk Molalla	Moderate	100	167,000			
North Fork Molalla	Moderate	100		91,000		
Gate Creek	Moderate	200			120	
Collowash River	High	300			180	
Abiqua Creek	High	300	500,000			
Thomas Creek	High	300		273,000		
Crabtree Creek[b]	High	300				
Calapooia River	Excellent	400			240	
Little N. Fk. Santiam	Excellent	400	668,000			
Horse Creek	Excellent	400		364,000		
Lost Creek[b]	Excellent	600				
			1,469,000	774,000	585	

a *To be adjusted by observed salmon populations.*
b *control.*

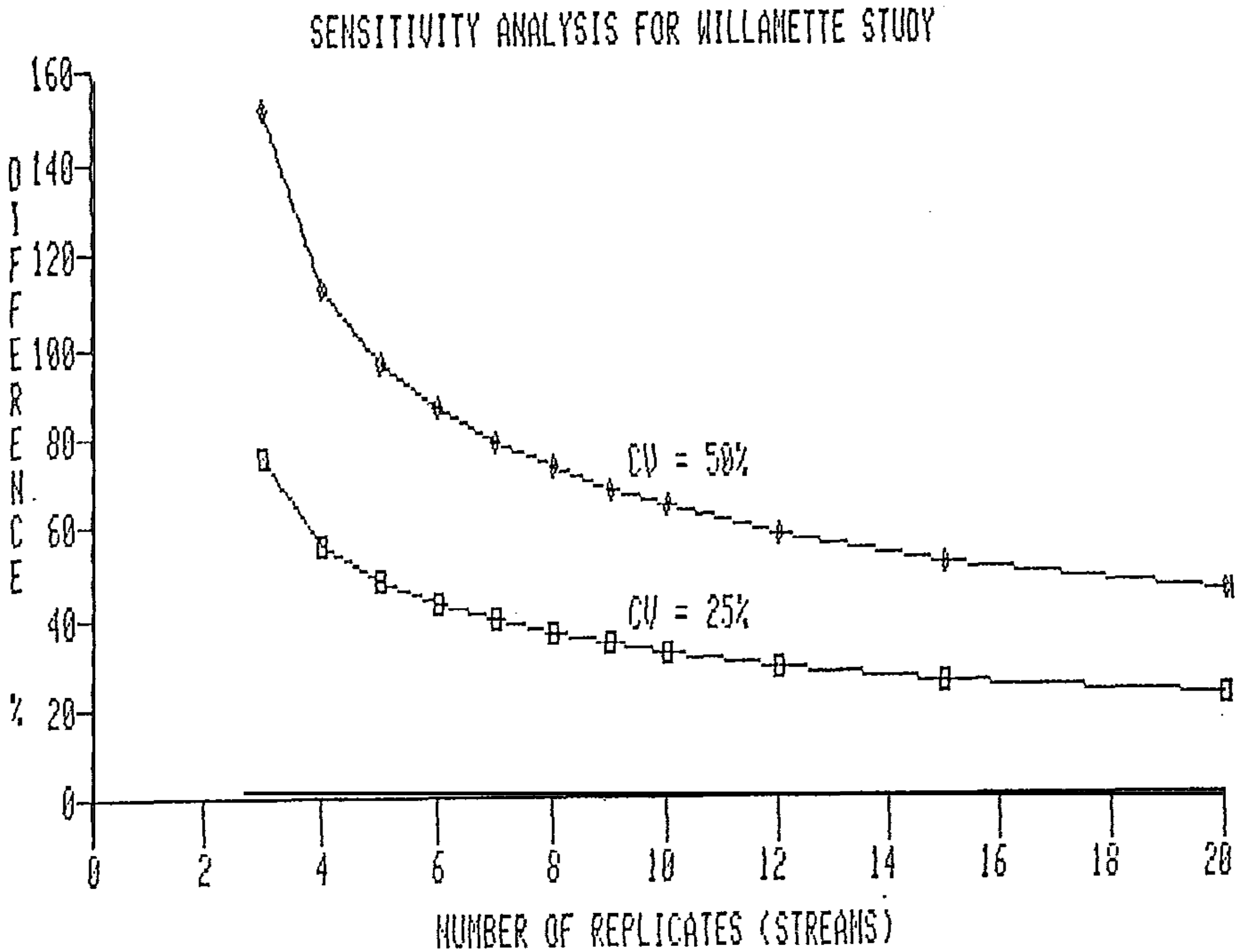

Figure 7. The minimum differences between treatments, expressed as a percentage of the overall mean numbers of fish returning, that would be detectable for different numbers of replicates and with two coefficients of variation (CV).

Table 8. Schematic for survey and stocking, Willamette basin supplementation study.

Brood year stocked	Age-class of adult return by *survey* year									
	1986[a]	1987[a]	1988[a]	1989	1990	1991	1992	1993	1994	1995
1986	....	 X	*Age*	*3*	Age 4	Age 5	Age 6	Sampling for Second Generation Effects		
1987	....	....	X		Age 3	Age 4	Age 5	Age 6		
1988	....	....	....	X		*Age 3*	Age 4	Age 5	Age 6	
1989	....	....	....	....	X		Age 3	Age 4	Age 5	Age 6

a stream sampling from 1986 to 1989 wilt provide baseline adult counts for use in calculating treatment effects.

stream-to-stream variations unassociated with stocking treatments will aid sensitivity of the analysis, but to an unknown degree.

Task 1.23

The purpose of this task is to give the details of the methods of population sampling.

Stream Surveys: Two teams of surveyors will be assembled: one team will be assigned to the eight "north valley" streams and the other team will be assigned to the eight "south valley" streams. The goal for each team will be to completely survey each of their assigned streams twice each year; once in the period 15 July-15 August, and again in the period 15 September-15 October. The early survey will count adults and the late survey will count detail spawning success redds and collect scales and vertebral centra from adults. Primary method of surveying will be snorkeling. Foot, boat, and aerial surveys will be used when practical.

Electrofishing: This method probably will not be employed because adult counts will be the parameter measured.

Weir Counts: Annual records will be kept of adult passage at Willamette Falls, North Fork Dam, and Leaburg Dam for use as covariates in explaining population variations.

Harvest: We will not intensively monitor harvest in the test and control streams. Many of the test streams are small and closed to salmon angling, and others receive but few adults in the legal salmon angling season, which generally closes 15 July in tributary areas. Where appropriate we will report catch by year from salmon catch cards (Hicks and Calvin 1964), but these data are often delayed.

Task 1.24

The purpose of this task is to prepare a tentative budget for evaluating outplants.

We estimated that conduct of the Phase 2 study including rearing and release of test fish, sampling of adults in test and control streams, data analyses, reporting, support services and administrative overview will require approximately 39 person-months of labor annually from FYI986 through FY 1995:

Name	Class	Months/year labor
E. J. Wagner	FWS-B	1
E. M. Smith	FWB-3	6
J. C. Zakel	FWB-2	6
W. H. Day	FWT-3	--
Vacant	(4) EBA-1	X 3 = 12
Vacant	Cler.Spec.	2
	Total	39

We project the first year of operation will require a total budget of $138,438, which includes approximately $5,000 in initial capital expenses (microcomputer and wet suits). A detailed budget projection has been provided to BPA.

References for Objective 1.2

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SUMMARY OF EXPENDITURES

Expenditures for Phase I (Literature Review and Project Development) of this study totalled the estimated budget sum $29,323. A copy of the original contract is in Appendix A.

These funds were expended as indicated in the budget proposal, without purchase of capital or "sensitive" items.

APPENDIX A

Contract #DE-A17g-85BP23109
Project/Task Order #85-68

	Original Contract
2-4-0-710-08-01/E. Wagner[1]	
Willamette Spawning study	
Personal Services	
Federal Funds	$20,485.00
Wildlife Funds	--
General Funds	--
Misc. Funds	--
Total	$20,485.00
Services/Supplies	
Federal Funds	$ 3,335.00
Wildlife Funds	--
General Funds	--
Misc. Funds	--
Total	$ 3,355.00
Capital Outlay	
Federal Funds	--
Wildlife Funds	--
General Funds	--
Misc. Funds	--
Total	--
Admin. Overhead	
Federal Funds	$ 5,483.00
Wildlife Funds	--
General Funds	--
Misc. Funds	--
Total	$ 5,483.00
Total	$29,323.00

1 *Effective dates 4/15/85 - 9/15/85.*

APPENDIX B

Supplementation Literature

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